



MATERIAL FOR PASSIVE

ELECTRONIC COMPONENTS

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This application is a continuation-in-part of *now abandoned*  
U.S. Application Serial No. 07/362,366, filed June 5, 1989.  
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08/118176

BACKGROUND OF THE INVENTION

The invention concerns a material for passive electronic components with high thermal conductivity, low density and low coefficient of thermal expansion.

The term "passive electronic components" here refers to those not directly involved in electronic activity. The invention relates more particularly to materials for making structures such as sinks, supports and pole pieces in power circuits, laser diode supports, heat sinks and encapsulating cases in hybrid microelectronic power circuits and ultra high frequency circuits. The term electronic also includes the optoelectronic field.

In the components in question these materials are known to be joined generally to insulating ceramic substances such as alumina or semiconductors such as silicon or gallium arsenide.

If the components include power elements, a large amount of heat is emitted when they operate. This has to be dissipated as rapidly as possible, to avoid damaging the components by excessive heating. A material of the highest possible thermal conductivity is therefore used.

The temperature nevertheless rises, and if the coefficient of thermal expansion of the material differs too much from that of the ceramic insulator or semiconductor substrate, the stresses which are set up in the substrate are greater than the resistance of the ceramic. The ceramic therefore breaks, impairing the efficiency of the whole unit.

Thus it is also necessary for the material to have a coefficient which is compatible with that of alumina or silicon and preferably below  $16 \times 10^{-6} \text{ K}^{-1}$  in the 30-400°C temperature range.

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The fact that these circuits may be used in vehicles driven by a source of energy has led to a search for materials with the lowest possible density, preferably below  $3100 \text{ kg.m.}^{-3}$ , in order to minimise the energy consumption required to propel the vehicles.

Since the circuits are affected by their surroundings, the material should also have a suitable amagnetic character and good resistance to the external environment.

A large amount of research has been carried out to find a material which would form a compromise between all these properties, and there have been more or less interesting findings.

Thus materials such as steel, beryllium and some aluminium alloys have been tried because of their good conductivity; but their relatively high modulus of elasticity and expansion capacity make it necessary to use joints or adhesives to accommodate the difference from the expansion capacity of the alumina, and this reduces the thermal conductivity of the whole unit.

Researchers then turned to materials with low expansion capacity, such as kovar (iron-nickel-cobalt alloy) or molybdenum or multi metal materials of the copper/invar/copper type as well as titanium and its alloys. But apart from molybdenum all these materials are handicapped by low conductivity, particularly in the direction perpendicular to the plane of the substrate. They all have high density also; the lowest density, that of titanium, is of the order of  $4500 \text{ kg.m.}^{-3}$ . In addition molybdenum is expensive and difficult to use

because of its poor resistance to oxidation; as for kovar, it is tricky to machine as it is twisted by internal stresses, and many annealing operations are necessary if it is to be worked correctly.

#### SUMMARY OF THE INVENTION

Hence applicants realised that there were deficiencies materials so far used. They therefore sought to develop a new material which would provide a compromise between the following properties:

- coefficient of thermal expansion : must be low and compatible with that of a ceramic such as alumina, silicon or gallium arsenide for a temperature variation of up to 400°C;
- thermal conductivity: as high as possible
- density: as low as possible
- imperviousness to the surroundings
- good resistance to corrosion
- appropriate machinability
- suitability for nickel, silver or gold plating
- suitability for welding
- ~~non-magnetic~~ character

Their research has led to an isotropic material for passive electronic components, i.e. one which has a mean coefficient of expansion between 30°C and 250°C of from  $2 \times 10^{-6} \cdot K^{-1}$  to  $13 \times 10^{-6} \cdot K^{-1}$  in all directions, a density of less than  $3100 \text{ kg.m}^{-3}$  and a thermal conductivity of over  $100 \text{ W.m}^{-1} \cdot K^{-1}$ . The structure is composite and the material is formed firstly by a metal from the group comprising aluminium and alloys thereof and magnesium and alloys thereof, and secondly by a ceramic from the group comprising particles of green silicon carbide and

polygranular graphite, the ceramic being used in proportions of from 50 to 90% by volume.

#### DETAILED DESCRIPTION OF THE INVENTION

In order to have very high conductivity, i.e. above  $150 \text{ W.m}^{-1} \text{K}^{-1}$ , a coefficient of expansion from  $7$  to  $13 \times 10^{-6} \text{ K}^{-1}$  and a Young's modulus higher than 120 GPa, it is preferable to use particles of green silicon carbide in proportions of from 50 to 75%.

If a lower coefficient of expansion, from  $4 \times 10^{-6}$  to  $10 \times 10^{-6} \text{ K}^{-1}$ , a lower density, below  $2300 \text{ kg.m}^{-3}$  and a Young's modulus below 50 GPa are required, though still with thermal conductivity higher than  $100 \text{ W.m}^{-1} \text{K}^{-1}$ , polygranular graphite should be used in proportions of from 65 to 90% by volume.

Thus the material of the invention differs from the previous ones, in that it does not just consist of one or more metals in a sandwich arrangement, but rather of polyphased mixtures of metal and ceramic with an isotropic structure.

The metal may be pure aluminium, pure magnesium or alloys thereof. These metals in fact combine good conductivity, low density and low melting point.

The alloys are chosen for their conductivity, in the realisation that it decreases according to the nature and quantity of the elements of addition, and that it decreases more when these elements are in solid solution than when they are in precipitate form.

In the case of aluminium alloys, those with few elements of addition are used. Zinc, copper, magnesium, iron and nickel can be tolerated in small quantities, whereas manganese, titanium, vanadium and lithium must be avoided.

It is preferable to use alloys in Aluminium Association series 1000, 5000 and 6000 and casting alloys. Among the casting alloys those containing 7, 10 and 13% of silicon are more particularly preferred, such as alloys A 356, A 357 and A 413.2, and in series 6000 alloys 6061 and 6101, as defined by Aluminium Association standards.

The material according to the invention also comprises ceramic elements in the form of equiaxed particles or porous polygranular bodies.

Not all ceramic elements are equally effective, and it is preferable to use those which have a low coefficient of thermal expansion, high thermal conductivity and low density.

More specifically, silicon carbide or polygranular graphite are used; these have properties which give an excellent compromise.

As far as the silicon carbide (SiC) particles are concerned, these are from 0.5 to 400 microns and more specifically from 3 to 50 microns in size.

If the composite obtained is to have high thermal conductivity, the particles of SiC must necessarily be very pure and contain over 99% by weight of SiC. This grade of SiC is usually described as "green SiC". According to the "Gmelin Handbook of Inorganic Chemistry"

8th edition, Supplement Vol.B3, p.60, ed. Springer Verlag  
1986, its composition is as follows:

% by weight

SiC	99.00 to 99.4
Free C	0.05 to 0.10
SiO <sub>2</sub>	0.40 to 0.60
Fe <sub>2</sub> O <sub>3</sub>	0.10 to 0.20
Al <sub>2</sub> O <sub>3</sub>	0.05 to 0.10

as compared with the "black SiC" normally used in prior art, which is of the following composition:

% by weight

SiC	98.75 to 99.2
Free C	0.10 to 0.15
SiO <sub>2</sub>	0.50 to 0.70
Fe <sub>2</sub> O <sub>3</sub>	0.10 to 0.20
Al <sub>2</sub> O <sub>3</sub>	0.25 to 0.35

As far as graphite is concerned, porous polygranular masses having individual grains smaller than 20 micron in size are used. The graphite grain has an equiaxed shape, and the graphite mass does not have any favored direction, so as to retain the isotropic character of the product. This particularly excludes any graphite fibres. The ceramic may be used in various forms known as porous preforms:

- either in the form of agglomerated particles, especially in the case of silicon carbide
- or in the form of polygranular masses, in the case of graphite.

p In the invention Applicants have used porous preforms in  
 B which the fraction of ceramic phase is over 50% and under  
 B 90% by volume. A fraction of less than 50% by volume  
 would in fact give the composite too high a coefficient of  
 B, 31, 19 expansion, over  $13 \times 10^{-6} \cdot K^{-1}$ , while a fraction of over 90%  
 by volume would create technical problems in production.

a The preform is then penetrated by the liquid metal by  
 B processes known in the art (see e.g. A.G. KELLY and G.I.  
 DAVIES, Metallurgical Reviews, 1965, Vol. 10 No. 37),  
 which may involve using applied pressure and/or  
 preheating; but any other known impregnating or moulding  
 method may be used (see patents <sup>pat. no. 4376804</sup> US 4376804, EP 0105890  
 and EP 045510 for example). A composite is formed with  
 interpenetrated networks of a ceramic phase and a metallic phase.  
 In the case of metal made of a series 6000 alloy, alloy  
 AA 356 or AA 357 or any alloy which may give rise to  
 structural hardening, the material, once moulded, is  
 subjected to heat treatment of the annealing or tempering  
 type to improve its mechanical properties.

The composite material thus obtained may require  
 additional machining and surface treatment operations  
 (nickel, silver or gold plating), which are well known in  
 the art.

The material can then give its associated active and/or  
 passive components bonding functions (in the case of a  
 support), bonding and heat dissipating functions (in the  
 case of a heat sink.), bonding, heat dissipating and  
 interconnecting functions (in the case of an  
 encapsulating case), or bonding, heat dissipating,  
 interconnecting functions or functions of protecting it



from its surroundings (in the case of a hermetically sealed encapsulating case).

In special cases where a hermetically sealed case is required, a case is first formed, the semiconductor elements or insulators and active circuits are placed inside it, and the case is closed with a cover which is fixed on by laser braze welding.

And finally, structures of the heat sink or support type may, if appropriate, be protected by a varnish or resin.

BRIEF DESCRIPTION OF THE DRAWING

The invention will be understood better from the accompanying figures, in which:

Figure 1 is a view in vertical section through an electronic component comprising a structure in the form of a heat sink for a power circuit;

Figure 2 is a plan view of the Figure 1 component;

Figure 3 is a view in vertical section through an electronic component comprising a structure in the form of an encapsulating case with its connections and cover;

and

Figure 4 is a plan view of the Figure 3 component, with the cover removed.

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DESCRIPTION OF THE PREFERRED EMBODIMENTS

In Figure 1, a heat sink 1 is made of material according to the invention, with an insulator 2 formed by a layer of alumina resting on it; an active circuit 3 is placed on the alumina and connected to its surroundings by input/output connections 4.

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a In Figure 2, the sink 1, its insulator 2, its active circuit 3 formed by thyristors 5, conductive tracks 6 and their connections 4, are shown.

P In Figure 3, a case 7 is made of material according to the invention, formed by a base 8 with a frame 9 resting on it. The frame contains holes 10 through which the connections 11 of the active circuits pass. A cover 12 is fixed inside the top of the frame.

P In Figure 4, a case 7 has base 8, frame 9 and connections 11. An insulator 13 rests on the base and active circuits 14 comprising conductive tracks 15 are placed on it. The bonds between the connections and the active circuits have not been shown.

P To ensure the dimensional stability and integrity of the interconnections in such assemblies when they are subjected to the thermal cycle, it is essential for the composite material to have the same thermal expansion coefficient in all directions. Only isotropic composite materials have therefore been used in the invention.

The invention is illustrated by the following examples.

EXAMPLE 1

Composite materials are produced, formed by a metal selected from alloys AA1050 and A357 and a ceramic in the form of black SiC particles of less than 99% purity and with numerous lattice impurities, or green SiC of over 99% purity with few lattice impurities, by the following method. A preform 120mm in diameter is obtained by filtering a suspension of SiC particles with an average size of 44.5 microns, containing colloidal silica to give it cohesion. When dried it contains 55% of particles and 5.5% of silica by volume. The preform is penetrated by the lost wax foundry moulding method. After solidification and demoulding, the composite material obtained has a density of  $2975 \text{ kg} \cdot \text{m}^{-3}$  corresponding to the theoretical value. The mean coefficient of expansion is  $10.5 \times 10^{-6} \cdot \text{K}^{-1}$  between 30 and  $250^\circ\text{C}$ . It is the same in all directions. The Young's modulus is 125 GPa and the bending strength 307 MPa. The electrical resistivity is 11 microhm-cm. The thermal conductivity of the composite material is calculated through measuring the thermal diffusivity and volumetric heat by the flash method. The experimental values (in  $\text{W} \cdot \text{m}^{-1} \cdot \text{K}^{-1}$ ) are given in the following table with the type of particles and the nature of the alloy.

	Thermal conductivity ( $\text{W} \cdot \text{m}^{-1} \cdot \text{K}^{-1}$ )	
	Black SiC	Green SiC
Alloy AA1070	122	170
Alloy A357	113	171

The purity of the SiC particles is found to have far more effect on the thermal conductivity of the composite material than the choice of alloy. Hence it is necessary to select SiC particles with a controlled content of lattice impurities, and with an SiC content of over 99% by weight (green SiC) in order to have conductivity above  $150 \text{ W} \cdot \text{m}^{-1} \cdot \text{K}^{-1}$ .

## EXAMPLE 2

A composite material is produced, containing alloy AA1090 and 18% by volume of ex. P.A.N. carbon fibres (polyacrylonitrile) graphited at  $2600^{\circ}\text{C}$ , with a density of about  $2500 \text{ kg} \cdot \text{m}^{-3}$ , a conductivity in the direction perpendicular to the plane of the fibres of  $164 \text{ W} \cdot \text{m}^{-1} \cdot \text{K}^{-1}$ , tangent coefficient of expansion at  $30^{\circ}\text{C}$  of the order of  $9 \times 10^{-6} \cdot \text{K}^{-1}$ , from 30 to  $250^{\circ}\text{C}$ , on the order of  $6 \cdot 4 \times 10^{-6} \cdot \text{K}^{-1}$ , and from 30 to  $400^{\circ}\text{C}$  on the order of  $3 \times 10^{-6} \cdot \text{K}^{-1}$  for measurements taken in the plane. On the otherhand, the coefficient of expansion from 30 to  $250^{\circ}\text{C}$  is  $55.5 \times 10^{-6} \cdot \text{K}^{-1}$  when measured in the direction normal to the plane.

This example shows that it is not advisable to use the ceramic phase in fibre form, since this makes the expansion properties very anisotropic.

In this case there is almost a factor of  $10^3$  between the coefficient of expansion in the plane and the coefficient of expansion normal to the plane.

cl EXAMPLE 3

Materials are made comprising a polygranular graphite (Carbone Lorraine reference S2457) and various aluminium and magnesium alloys. The alloys are aluminium of over 99.7% purity (AA1070), aluminium containing 5% of magnesium (AG5), aluminium containing 5% of nickel (AN5), aluminium containing 7% of silicon and 0.6% of magnesium (A 357) and magnesium containing 5% of zinc and about 1% of rare earths (RZ5).

When the composite materials have solidified and been demoulded, their properties of expansion, thermal conductivity, density and in some cases also elasticity, rigidity and electric resistivity are determined. All the properties obtained are isotropic.

The results are given in the table.

Matrix	Coefficient of thermal expansion from 30 to 250°C	Thermal conductivity	Density	Young's modulus	Bending strength	Electrical resistivity
	$10^{-6} \cdot K^{-1}$	$W.m^{-1} \cdot K^{-1}$	$kg.m^{-3}$	GPa	MPa	Microhm-cm
AA1070	6.0	133	2200	20	58	125
A357	7.4	142	2200	23	128	150
AG5	7.9	124	2200	-	-	-
AN5	5.3	124	2200	-	-	-
RZ5	6.5	128	1700	-	-	-

The various compositions of aluminium and magnesium based alloys give different compromises between properties. It will be noted in particular that coefficients of expansion very close to those of alumina or gallium arsenide can be obtained while still keeping very high thermal conductivity.

#### EXAMPLE 4

Composite materials are made comprising various types of polygranular graphite with different densities (Carbone Lorraine references S2512 - S2457 - S2545) and an aluminium of over 99.7% purity. The proportion of graphite in the composites is from 50 to 90 volume percent.

Composites are obtained after impregnation and demoulding, and their properties of expansion, thermal conductivity, density and in some cases elasticity, rigidity and electric resistivity are determined. All the properties obtained are isotropic.

The results are set out in the table below.

Volumic fraction of graphite	Graphite reference	Coefficient of thermal expansion from 30 to 250°C	Thermal conductivity	Density	Young' modulus	Bending strength	Electrical resistivity
%		$10^{-6} \cdot K^{-1}$	$W.m.^{-1} \cdot K^{-1}$	$kg/m^{-3}$	GPa	MPa	Microhm-cm
82	S2512	2.9	113	2200	18	72	-
69	S2457	6.0	133	2200	20	58	125
60	S2545	10.0	129	2300	25	32	25

es The different grades of graphite give different compromises between properties. It will be observed in particular that graphite grade S2512 gives a coefficient of expansion equivalent to that e.g. of silicon or aluminum nitride.

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All the composite materials and composite structures obtained from the materials described in Examples 1 to 4 have a mean coefficient of thermal expansion, from 30 to 250°C, of under  $13 \times 10^{-6} \text{ . K}^{-1}$  and over  $2 \times 10^{-6} \text{ . K}^{-1}$  and thermal conductivity over  $100 \text{ W. m}^{-1} \text{ . K}^{-1}$  in all directions. These properties are given in Table I.

TABLE I  
ISOTROPIC MATERIALS AND STRUCTURES

Composite	Coefficient of thermal expansion from 30 to 250°C $10^{-6} \text{ . K}^{-1}$	Thermal conductivity $\text{W.m}^{-1} \text{ . K}^{-1}$
Green SiC particles AA 1070	10.5	170
S2545 polygranular graphite/AA1070	10.0	129
S2457 polygranular graphite/AG5	7.9	124
S2457 polygranular graphite/A357	7.4	142
S2457 polygranular graphite RZ5	6.5	128
S2457 polygranular graphite/AA1070	6	133
S2457 polygranular graphite/AN5	5.3	124
S2512 polygranular graphite/AA1070	2.9	113